TITLE

IMPROVED METHODS AND APPARATUS FOR GRAVEL PACKING OR FRAC PACKING WELLS

CROSS-REFERENCE TO RELATED APPLICATIONS

Not applicable

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

Not applicable

REFERENCE TO MICROFICHE APPENDIX

Not applicable

TECHNICAL FIELD

[0001] This invention relates to improved methods and apparatus for completing wells, and more particularly, to improved methods and apparatus for gravel packing or frac packing by providing multiple flow paths for slurry flow via blank (nonperforated) tube segments in the well annulus.

BACKGROUND OF THE INVENTION

[0002] The production of hydrocarbons from unconsolidated or poorly consolidated formations may result in the production of sand along with the hydrocarbons. The presence of formation fines and sand is disadvantageous and undesirable in that the particles abrade pumping and other producing equipment and reduce the fluid production capabilities of the producing zones in the wells.

[0003] Particulate material (*e.g.*, sand) may be present due to the nature of a subterranean formation and/or as a result of well stimulation treatments wherein proppant is introduced into a subterranean formation. Unconsolidated subterranean zones may be stimulated by creating fractures in the zones and depositing particulate proppant material in the fractures to maintain them in open positions.

[0004] Gravel packs with sand screens and the like have commonly been installed in wellbores penetrating unconsolidated zones to control sand production from a well. The gravel packs serve as filters and help to assure that fines and sand do not migrate with produced fluids into the wellbore.

[0005] Cased-hole gravel packing requires that the perforations or fractures extending past any near-wellbore damage as well as the annular area between the outside diameter (OD) of the screen and the inside diameter (ID) of the casing be tightly packed with gravel. *See* Brochure: "Sand Control Applications," by Halliburton Energy Services Inc., which is incorporated herein by

reference for all purposes. The open-hole gravel-pack completion process requires only that the gravel be tightly packed in the annulus between the OD of the screen and the openhole.

[0006] Several techniques to improve external gravel-pack placement, either with or without fracture stimulation, have been devised. These improved techniques can be performed either with the gravel-pack screen and other downhole equipment in place or before the screen is placed across the perforations. The preferred packing methods are either 1) prepacking or 2) placing the external pack with screens in place, combined with some sort of stimulation (acid-prepack), or with fracturing or acidizing. The "acid-prepack" method is a combination stimulation and sand control procedure for external gravel-pack placement (packing the perforations with gravel). Alternating stages of acid and gravel slurry are pumped during the treatment. The perforations are cleaned and then "prepacked" with pack sand.

[0007] Combination methods combine technologies of both chemical consolidation and mechanical sand-control. Sand control by chemical consolidation involves the process of injecting chemicals into the naturally unconsolidated formation to provide grain-to-grain cementation. Sand control by resin-coated gravel involves placing a resin-coated gravel in the perforation tunnels. Resin-coated gravel is typically pumped as a gel/gravel slurry. Once the resin-coated gravel is in place, the resin sets up to form a consolidated gravel filter, thereby removing the need for a screen to hold the gravel in place. The proppant pumped in a frac treatment may be consolidated into a solid (but permeable) mass to prevent proppant-flow back without a mechanical screen and to prevent formation sand production. U.S. Pat. No. 5,775,425, which is incorporated herein by reference for all purposes, discloses an improved method for controlling fine particulates produced during a stimulation treatment, including the steps of providing a fluid suspension including a mixture of a particulate coated with a tackifying compound and pumping the suspension into a formation and depositing the mixture within the formation.

[0008] A combined fracturing and gravel-packing operation involves pumping gravel or proppant into the perforations at rates and pressures that exceed the parting pressure of the formation. The fracture provides stimulation and enhances the effectiveness of the gravel-pack operation in eliminating sand production. The fracturing operation produces some "restressing" of the formation, which tends to reduce sanding tendencies. *See* Brochure: "STIMPAC Service Brochure," by Schlumberger Limited, which is incorporated herein by reference for all purposes. The high pressures used during fracturing ensure leakoff into all perforations, including those not connected to the fracture, packing them thoroughly. Fracturing and gravel packing can be combined as a single operation while a screen is in the well.

[0009] "Fracpacking" (also referred to as "HPF," for high-permeability fracturing) uses the tip-screenout (TSO) design, which creates a wide, very high sand concentration propped fracture at the wellbore. *See* M. Economides, L. Watters & S. Dunn-Norman, *Petroleum Well Construction*, at 537-42 (1998), which is incorporated herein by reference for all purposes. The

TSO occurs when sufficient proppant has concentrated at the leading edge of the fracture to prevent further fracture extension. Once fracture growth has been arrested (assuming the pump rate is larger than the rate of leakoff to the formation), continued pumping will inflate the fracture (increase fracture width). The result is short but exceptionally wide fractures. The fracpack can be performed either with a screen and gravel-pack packer in place or in open casing using a squeeze packer. Synthetic proppants are frequently used for fracpacks since they are more resistant to crushing and have higher permeability under high confining stress.

[0010] In a typical gravel pack completion, a screen consisting of screen units, which are connected together, is placed in the wellbore within the zone to be completed. The screen is typically connected to a tool having a packer and a crossover. The tool is in turn connected to a work or production string. A particulate material, usually graded sand (often referred to in the art as gravel) is pumped in a slurry down the work or production string and through the crossover whereby it flows into the annulus between the screen and the wellbore. The liquid forming the slurry leaks off into the subterranean zone and/or through a screen sized to prevent the sand in the slurry from flowing there through. As a result, the sand is deposited in the annulus around the screen whereby it forms a gravel pack. The size of the sand in the gravel pack is selected such that it prevents formation fines and sand from flowing into the wellbore with produced fluids.

[0011] Circulation packing (sometimes called "conventional" gravel-packing) begins at the bottom of the screen and packs upward along the length of the screen. Gravel is transported into the annulus between the screen and casing (or the screen and the open hole) where it is packed into position from the bottom of the completion interval upward. The transport fluid then returns to the annulus through the washpipe inside the screen that is connected to the workstring.

[0012] Horizontal gravel packs can be placed in open or cased hole completions of varying lengths. The alpha/beta wave approach has been used extensively for gravel packing horizontal wells. This method is a two-step procedure, which includes an alpha wave sand deposition in one direction and a beta wave sand deposition in the opposite direction. *See* M. Economides, L. Watters & S. Dunn-Norman, *Petroleum Well Construction*, at 533-34 (1998), which is incorporated herein by reference for all purposes. Water-based sand slurry is pumped down the vertical work string out the horizontal portion of the screen-casing annulus. A sand dune builds up in the borehole both in the forward direction (away from the vertical borehole) and in the reverse direction (back toward the vertical borehole). The sand dune fills the horizontal borehold annulus to about 50% to over 80% fill (the alpha sand wave deposition). The leading edge of the sand dune progresses toward the toe of the wellbore until it reaches the end of the screen. Then the beta wave deposition of sand in the horizontal borehole begins. The sand movement in the beta deposition occurs in successive waves. However, this approach depends on maintaining a very limited fluid loss. If fluid loss is too great, it will stall wave development, causing a bridge to form that prevents the annular pack from being completed.

[0013] A problem often encountered in forming gravel packs, particularly gravel packs in long and/or deviated unconsolidated producing intervals, is the formation of sand bridges in the annulus between the sand retainer screen and the casing wall (for in-casing gravel packs) or the formation (for open-hole gravel packs). Non-uniform sand packing often occurs as a result of the loss of carrier liquid from the sand slurry into high permeability portions of the subterranean zone. This in turn causes the formation of sand bridges before all the sand has been placed. Sand bridges in the interval to be packed prevent placement of sufficient sand below that bridge for top-down gravel packing, or above that bridge for bottom-up gravel packing. When the well is placed on production, the flow of produced fluids is concentrated through the voids in the gravel pack, which soon causes the screen to be eroded, and the migration of fines and sand with the produced fluids to result.

[0014] The key to successful frac packs and gravel packs is the quantity of gravel placed in the fracture, perforations and casing/screen annulus. The development of bridges in long perforated intervals or highly deviated wells can end the treatment prematurely, resulting in reduced production from unpacked perforations, voids in the annular gravel pack, and/or reduced fracture width and conductivity.

[0015] To prevent the formation of sand bridges and create uniform distribution during gravel packing, "alternate-path" (or "multiple-path") well screens using perforated "shunt tubes" extending along the screen have been proposed. *See, e.g.*, Jones, L.G., et al.: "Alternate Path Gravel Packing," SPE 22796, 1991, which is incorporated by reference herein for all purposes. In these well screens, the alternate-paths (*e.g.*, perforated shunts or by-pass conduits) extend along the length of the screen and are in fluid communication with the gravel slurry as the slurry enters the well annulus around the screen. If a sand bridge forms in the annulus, the slurry is still free to flow through the conduits and out into the annulus through the perforations in the shunt tubes to complete the filling of the annulus above and/or below the sand bridge.

[0016] Shunt technology is suited for frac-packing. *See* L. Jones: "Spectacular Wells Result From Alternate Path Technology," article reprint from Petroleum Engineer International, which is incorporated by reference herein for all purposes. When a shunt system is placed in the squeeze position, the slurry dehydrates as with any fracturing operation until the pack in the fracture builds back into the annulus at some high leak-off location. Then, instead of a sand out, the slurry bypasses the bridge through the shunts and finishes packing the downstream interval. The shunts can be used in multiple intervals isolated by packers. *See* Brochure: "Alternate Path Service Brochure," by Schlumberger Limited, which is incorporated herein for all purposes. The shunts are compatible with cup-type annular packers. Different sized tubes can be used for treating and packing different intervals. Shunts in different sizes can result in different flow rates.

[0017] In many alternate-path well screens, the individual shunt tubes are carried externally on the outer surface of the screen. U.S. Pat. No. 4,945,991, which is incorporated herein

by reference for all purposes, proposes a well screen with perforated shunt tubes attached to the outside of a screen. This patent proposed attaching long, perforated shunt tubes to the exterior of the screen to form a continuous shunt path extending along the entire length of the screen, even when the screen was comprised of multiple sections. The shunt tubes were connected together between all sectional lengths of the screen, to provide a continuous flow path along the exterior of the screen sections for the gravel-laden fluid. (The patents and/or other references mentioned in the Background Section are not admitted to be "prior art" with respect to the present invention merely because they are mentioned herein).

[0018] As explained at col. 1, ln. 66 - col. 2, ln. 24 in U.S. Pat. No. 6,220,345 external shunt tubes suffer from numerous disadvantages and problems. Problems with the device of U.S. Pat. No. 4,945,991 are that it is troublesome to hang down the device in the wellbore and it is difficult to lift up the device from the wellbore due to the danger of the screen sticking to the wellbore. Besides, it is extremely difficult to connect respective shunt tubes attached to the outside of the screen to shunt tubes attached to the outside of a following screen in the course of assembling the screen and lowering it into the wellbore.

[0019] Another disadvantage in mounting the shunts externally is that the shunts are exposed to damage during assembly and installation of the screen. Due to the relative small size of the alternate-path shunt tubes, it is vitally important that they are not crimped or otherwise damaged during the installation of the screen. One proposal for protecting these shunts is to place them inside the outer surface of the screen; *see, e.g.*, U.S. Pat. Nos. 5,476,143 and 5,515,915, which are incorporated herein by reference for all purposes. However, it may be more desirable from an economic standpoint to merely position and secure the by-pass conduits or shunt tubes onto the external surface of a commercially-available well screen.

[0020] Another technique proposed for protecting externally positioned shunt tubes involves concentrically mounting a perforated, protective shroud over the screen and the associated shunt tubes. U.S. Pat. No. 5,934,376, which is incorporated herein by reference for all purposes, discloses a new method, called CAPS™, for concentric annular pack screen system, basically comprising the steps of placing a perforated shroud with an internal sand screen disposed therein, in the zone to be completed, isolating the perforated shroud and the wellbore in the zone and injecting particulate material into the annuli between the sand screen and the perforated shroud and the wellbore to thereby form packs of particulate material therein. The system enables the fluid and sand to bypass any bridges that may form by providing multiple flow paths via the perforated shroud/screen annulus. The shroud protects the screen during placement and prevents subsidence problems during production.

[0021] U.S. Pat. No. 5,890,533, which is incorporated herein by reference for all purposes, proposes a gravel-pack, well screen having a shunt tube positioned inside the base pipe of the screen. The shunt tube extends substantially throughout the length of the base pipe. A

threaded connector or the like is provided on either end of the length of the internal shunt tube to connect the adjacent lengths of shunt tube together.

[0022] As mentioned, it is also difficult and time consuming to make all the fluid connections between the respective shunt tubes which are required in making-up a typical alternate-path well screen. The use of thread joints to interconnect adjacent lengths or joints of screen often makes it difficult to circumferentially align each pair of shunt tubes that must be interconnected to maintain axial continuity in the overall shunt flow path. Additionally, a supplemental connection fitting must be used to interconnect and operatively communicate the interiors of each pair of shunt tubes to be connected.

[0023] For example, the length of a typical alternate-path well screen is normally substantial (*e.g.*, 1000 feet or more) and is made up of a plurality of 20 foot or longer joints. Each joint is basically similar to the others in that they all are comprised of a permeable section (*i.e.*, length of screen material) having a plurality of axially-extending, individual shunt tubes positioned thereon. In making-up or assembling most of these alternate-path well screens, the desired number of joints are secured together by first coupling the "base pipes" of the screen joints together and then individually, fluidly connecting each of the shunt tubes on a joint to its respective shunt tube on the adjacent joint. Since a typical joint normally has a plurality of parallel, axially-extending shunt tubes thereon with individual connections for each shunt tube is required in making up the necessary fluid connections between the shunt tubes of any two adjacent joints thereby requiring eight different physical manipulations for each joint (*i.e.*, one at each end of each individual connector).

[0024] One proposed technique for reducing both the number of connectors and the time required in assembling an alternate-path screen is contained in U.S. Pat. No. 5,390,966, which is incorporated herein by reference for all purposes, and wherein a single connector is used to make a fluid connection between four sets of respective shunt tubes. This device still requires that each shunt tube be substantially aligned with its respective shunt tube on an adjacent joint before the single connector will function.

[0025] U.S. Pat. No. 5,868,200, which is incorporated herein by reference for all purposes, proposes an alternate-path, well screen made-up of joints and having a sleeve positioned between the ends of adjacent joints which acts as a manifold for fluidly-connecting the alternate-paths on one joint with the alternate-paths on an adjacent joint. These sleeves surround the respective lower and upper ends of the shunt tubes on adjacent screen joints, which are to be fluidly connected. The sleeves are affixed to the joints, by threads, welding, etc. In some instances, a sealing means (*e.g.*, O-rings or the like) may be required between the sleeves and the joints, to prevent excessive leakage at the manifolding of the joints together. The alternate flowpaths are comprised of perforated conduits, which extend longitudinally along the external surface of the screen. To protect the shunt tubes, a protective shroud is concentrically positioned

about each screen joint. The shroud has a plurality of openings through the wall thereof to provide an exit for fluid (*e.g.*, gravel slurry) to pass out of the shroud as it flows out the openings in the shunt tubes and an entrance for fluids into the shroud and through the permeable section of the screen during production.

[0026] Another problem that may arise in typical alternate-path well screens is in maintaining adequate and consistent flow of fluid through the relatively small perforations (or "exit ports") at each of the delivery points along the lengths of the shunt tubes. For example, the flow of the gravel-laden slurry in a gravel pack operation is substantially parallel to the axis of the delivery or shunt tubes until the slurry reaches the respective exit ports along the length of a shunt tube. The flow must then make a "right-angle" turn before it can flow through a respective exit port. This results in a tendency for at least some of the particulates (*i.e.*, sand) to by-pass the ports. This, in turn, causes the sand concentration of the carrier fluid to build-up inside the shunt tube thereby adversely affecting the distribution of the gravel pack. In fracturing operations, at least a portion of any particles (*e.g.*, sand) in the fracturing fluid will have the same tendency to by-pass the exit ports and build-up within the delivery conduit of the tool. This results in a diluted fracturing fluid (*i.e.*, lower concentration of sand) being delivered through the exit ports. Further, in order to maintain the proper pressures at each level along the tool and to prevent premature dehydration of the slurry, each of the exit ports must be relatively small. Unfortunately, the small size (*e.g.*, diameter) of the exit ports severely restricts the volume of fracturing fluid, which can be delivered to each fracturing level thereby further adversely affecting the fracturing operation. Too many holes will provide too much leak-off from the shunts and reduce shunt fluid velocities. Plugging of smaller shunt holes is also a problem.

[0027] Thus, there are needs for improved methods and apparatus for completing wells, including providing a simpler, more cost-effective system that uses the alternate path or "bridging bypass" phenomenon to enhance gravel packing and fracturing operations.

SUMMARY

[0028] The present invention provides improved methods and apparatus for completing wells, including gravel packing and frac packing operations, which meet the needs described above and overcome the deficiencies of the prior art. More specifically, the present invention provides an alternate-path, well screen without requiring that the alternate paths (*i.e.*, delivery or shunt tubes) on adjacent joints of screen be axially aligned or individually connected. This allows the joints to be made-up quickly which speeds up the assembly and installation of the alternate-path, well screen. The delivery tubes (as opposed to the relatively smaller shunt-tube perforations, in typical alternate-path well screens) provide alternate flow paths for the sand-laden fluid to reach the well annulus, so larger volumes of fluid can be delivered and premature dehydration of the

slurry and/or sand build-up within the tubes is inhibited. No structure projecting outside the screen such as shunt tubes is provided and therefore, there is no danger of the screen sticking to the wellbore when the screen is lowered or lifted through the wellbore.

[0029] The improved methods basically comprise the steps of placing a sand screen (*e.g.*, screens, screened pipes, slotted liners, prepacked screens, etc.) in the wellbore adjacent the zone to be completed, positioning an alternate flowpath comprised of a plurality of blank (non-perforated) tube segments which are open at both ends in the annulus between the sand screen and the wellbore, isolating the annulus between the screen and the wellbore in the zone, and injecting particulate material into the annulus between the sand screen and the wellbore and into the zone, whereby the particulate material is uniformly packed into the annulus between the sand screen and the zone. As used herein, the terms "blank tubes" or "conduits" are used to define a structure forming an elongated closed fluid passageway effectively having only two spaced opening points for flow into and out of the passageway. The permeable pack of particulate material formed prevents the migration of formation fines and sand with fluids produced into the wellbore from the unconsolidated zone.

[0030] The present alternate-path, well screen is comprised of one or more basically identical screen joints (or "screen units"). A threaded coupling or the like is provided on either end of the base pipe of the screen joints to connect adjacent joints together. The improved well screen has a cross-over sub or the like attached at its upper end which, in turn, is connected to and suspended in the wellbore by a work string or tubing string.

[0031] The alternate-paths (*e.g.*, blank tube segments) are secured or otherwise provided on the external surface of the screen for delivering a gravel slurry to the interval of the wellbore being completed. The blank tubes extend in the axial direction of the screen disposed cylindrically at a predetermined interval in the circumferential direction of the screen. Each of the blank tubes extends only a portion of the length of the screen. The blank tubes are open at both ends and adapted to receive the gravel slurry as it reaches the apparatus and direct it to the interval. The upper and lower ends of the blank tubes preferably have an arcuate or beveled shape. If a sand bridge forms in the annulus between the sand screen and the wellbore, the slurry is still free to flow through the blank tubes and out into the annulus through the lower, open lower ends of the blank tubes to complete the filling of the annulus above and/or below the sand bridge. The use of the larger (in area) open, lower ends of the delivery tubes to deliver the slurry to the well annulus alleviates the problem of the relatively smaller exit ports along the length of a typical shunt tube often becoming blocked with sand prior to the completion of the operation.

[0032] In some instances, it may be desirable to also include a protective shroud mounted over the sand screen and the associated multiple flowpaths (*e.g.*, blank tubes) to protect the alternate flowpaths during installation of the well screen. In such instances, the protective shroud has a plurality of openings in the wall thereof to allow fluid from the lower, open ends of the blank

tubes to flow through the shroud and into the well annulus during a gravel pack operation and for fluids to flow into the shroud and through the sand screen during production.

[0033] The present methods can be combined with other techniques, such as prepacking, fracturing, chemical consolidation, etc. The methods may be applied at the time of completion or later in the well's life. The unconsolidated formation can be fractured prior to or during the injection of the particulate material into the unconsolidated producing zone, and the particulate material can be deposited in the fractures as well as in the annulus between the sand screen and the wellbore.

[0034] The improved spacing methods and apparatus of this invention provide a simpler, more cost-effective system with multiple paths, so that a slurry can bypass any premature annulus bridges that form during gravel packing or frac packing and halt the packing process. The system may be used in long intervals and variable formations.

[0035] Other and further objects, features and advantages of the present invention will be readily apparent to those skilled in the art upon a reading of the description of preferred embodiments which follows when taken in conjunction with the accompanying drawings, in which:

DESCRIPTION OF THE DRAWINGS

[0036] FIG. 1 is a schematic view illustrating a well screen structure embodying principles of the present invention located in an eccentric position within a horizontal open-hole wellbore adjacent a subterranean zone to be completed;

[0037] FIG. 2 is a cross-sectional view of the configuration of FIG. 1;

[0038] FIG. 3 is a partial sectional view taken along line 3-3 in FIG. 2, looking in the direction of the arrows;

[0039] FIG. 4 is a partial sectional view of one embodiment of a perforated shroud concentrically mounted over a sand screen having alternate flowpaths in accordance with the present invention;

[0040] FIGS. 5A to 5D illustrate shrouds laid flat prior to forming into a cylindrical shape with variations of configurations of blank tubes in accordance with the present invention;

[0041] FIG. 6 is an elevation view, partly in section, of a further embodiment of a well tool having alternate flowpaths in accordance with the present invention;

[0042] FIG. 7 is an elevation view, partly in section, of still another embodiment of a well tool having alternate flowpaths in accordance with the present invention; and

[0043] FIG. 8 is a detail view of an alternative embodiment.

DETAILED DESCRIPTION OF THE INVENTION

[0044] The present invention provides improved methods and apparatus for completing, and optionally simultaneously fracture stimulating, a subterranean zone penetrated by a wellbore. The methods can be performed in either vertical or horizontal wellbores, and in "open-hole" and/or under reamed completions as well as in cased wells. If the method is to be carried out in a cased wellbore, the casing is perforated to provide for fluid communication with the zone. The term "vertical wellbore" is used herein to mean the portion of a wellbore in an unconsolidated or poorly consolidated subterranean producing zone to be completed which is substantially vertical or deviated from vertical in an amount up to about 15°. The term "horizontal wellbore" is used herein to mean the portion of a wellbore in an unconsolidated or poorly consolidated subterranean producing zone to be completed, which is substantially horizontal, or at an angle from vertical in the range of from about 75° to about 105°. Since the present invention is applicable in horizontal and inclined wellbores, the terms "upper and lower," "top and bottom," as used herein are relative terms and are intended to apply to the respective positions within a particular wellbore, while the term "levels" is meant to refer to respective spaced positions along the wellbore.

[0045] Referring more particularly to the drawings, FIG. 1 illustrates a horizontal open-hole wellbore 10. The wellbore 10 extends into an unconsolidated subterranean zone 12 from a cased wellbore extending to the surface. As mentioned, while wellbore 10 is illustrated as a horizontal open-hole completion it should be recognized that the present invention is also applicable to vertical-cased wellbores; *e.g.*, as illustrated in U.S. Pat. No. 5,341,880, which is incorporated herein by reference for all purposes.

[0046] A sand screen assembly 21 is located inside wellbore 10. Sand screen 21 has a "cross-over" sub connected to its upper end, which is suspended from the surface on a tubing or work string (not shown). A packer 26 is attached to the crossover. The cross-over and packer 26 are conventional gravel pack forming tools and are well known to those skilled in the art. The packer 26 is used to permit crossover during packing. The crossover provides channels for the circulation of proppant slurry to the outside of the screen 21 and returns circulation of fluid through the screen 21 and up the washpipe 40. The washpipe 40 is attached to the gravel pack service tool and is run inside the screen 21. The washpipe 40 is used to force fluid to flow around the bottom of the screen 21.

[0047] Sand screen assembly 21 may be of a single length or it may be comprised of a plurality of screen units 35 which are connected together with threaded couplings or the like (not shown). As shown, each of the screen units 35 is basically identical to each other and each is comprised of a perforated base pipe 36 having a continuous length of wrap wire 37 wound thereon, which forms a "screen section" therein. Metal ribs 38 are welded longitudinally on the outside of the base pipe 36. Then the wire ribbon 37 is wrapped around the metal ribs 38 in a helical pattern. While base pipe 36 is shown as having a plurality of perforations 39 therein, other types of

permeable base pipes, *e.g.*, slotted pipe, etc., can be used without departing from the present invention. Each coil of the wrap wire 37 is slightly spaced from the adjacent coils to thereby form fluid passageways (not shown) between the respective coils of wire as is commonly done in many commercially-available, wire-wrap screens.

[0048] The term "screen" is used generically herein and is meant to include and cover all types of similar structures which are commonly used in gravel pack well completions which permit flow of fluids through the "screen" while blocking the flow of particulates (*e.g.*, other commercially-available screens; slotted or perforated liners or pipes; sintered-metal screens; sintered-sized, mesh screens; screened pipes; pre-packed screens, radially-expandable screens and/or liners; or combinations thereof).

[0049] Multiple flowpaths comprised of a plurality (five in the embodiment shown in FIG. 2) of blank (non-perforated) tube segments 30 are positioned about the external surface of screen 21. Blank tubes 30 can be attached to or positioned along the outer surface of the screen 21. As shown in the drawings, blank tubes 30 extend in the axial direction of the screen 21 and are equidistantly provided in the circumferential direction of screen 21. Each of the blank tubes 30 extends only a portion of the length of screen 21. The blank tubes 30 typically have parameters of about ⅜ inch to 1-inch ID and 4 to 20 feet in length. Blank tubes 30 may be of equal lengths (as shown) or they may be of different or varying lengths. Although the blank tubes 30 may be made of any pressure-resistant material, they are preferably made of stainless steel.

[0050] The blank tubes 30 are open at their upper ends 34 and lower ends 33 to establish fluid communication between blank tubes 30 and the screen/wellbore annulus. Although in the illustrated embodiments the blank tube openings are located at the tube ends, it is understood that one or more of the two openings could be spaced from the end. These openings are sized to permit blank tubes 30 to receive the gravel slurry as it reaches the apparatus and direct the slurry to the interval of the wellbore being completed.

[0051] If desired, a protective shroud 20 can be concentrically mounted over the screen 21 and the blank tubes 30. If present, the perforated shroud 20 is of a diameter such that when it is disposed within the wellbore 10 an annulus 23 is formed between it and the wellbore 10. Perforated shroud 20 has perforations or slots 24 which can be circular as illustrated in the drawings, or they can be rectangular or other shapes. Shroud hole size should be engineered based on the rheology of the carrier fluid, the pump rate and production considerations. Generally, when circular slots are utilized they are at least ¼ in. in diameter, and when rectangular slots are utilized they are at least ¼ in. wide by ½ in. long.

[0052] Blank tubes 30 may be mounted internally on shroud 20 as shown in FIG. 2, or they may be mounted externally on shroud 20. However, blank tubes 30 are preferably positioned within shroud 20 to protect them from damage and abuse during handling and installation of the well screen. Blank tubes 30 can also act as centralizers for the screen 21 if they are installed inside

shroud 20. The shroud 20 can protect the screen 21 when it is installed in the wellbore, such as from invasion of mud cake or mechanical damage. The screen 21 will then slide on the smooth surface of the shroud 20, instead of being dragged on the rugged wellbore wall, layered with mud cake.

[0053] Blank tubes 30 can be round as shown in the drawings, or they can have other shapes, such as oval, square, rectangular, polygonal, etc. In some instances, round tubes are preferably used since it is easier and less expensive to manufacture round tubes and a round tube has a greater and more uniform burst strength than a comparable rectangular tube. Blank tubes 30 can be separately formed, or the sand screen 21 (or slotted liner 20, if present) may be utilized as part of the structure constituting the blank tubes 30 so that material can be saved and the screen structure can be simplified, and the weight of the screen can be held at a minimum. The number of blank tubes 30 used can be one or more, but at least four are preferably used.

[0054] Blank tubes 30 can be comprised of a variety of different configurations and/or arrangements. Blank tubes 30 may be axially aligned (*e.g.*, directly across from each other), or they may be offset. Blank tubes 30 can be configured, for example, in any combination of the arrangements shown in FIGS. 5A to 5D. In these figures, the shroud 20 is shown as a perforated sheet of material prior to rolling the sheet into a cylindrical or tubular shape. According to the present invention sheet material is formed into a cylindrical shape with edges 20a and 20b abutting and welded together. It is anticipated that tubes 30 preferably are welded to the sheet-forming shroud 20 before it is formed into a cylinder. In FIG. 5A, the tubes 30 are shown arranged in a parallel pattern with the respective upper and lower ends 34 and 33 of adjacent tubes aligned. If the blank tubes 30 are axially aligned their respective facing ends are spaced apart a sufficient distance to cause the slurry exiting one tube to mix with the surrounding material before entering the adjacent axially aligned tube. If blank tubes 30 are axially aligned, the facing end portions of each axially adjacent pair of blank tubes 30 are preferably spaced at least ¼ inch apart. The axial spacing of the ends of the tubes 30 allows joints 42 between adjacent screen sections to be made-up (connected) without necessity of connecting the axially spaced tubes 30 (also see FIG. 1). The configuration of FIG. 5A could be included with the patterns shown in FIGS. 5B–5E. In FIG. 5B the ends of adjacent rows of tubes 30 are staggered along the length of the sand screen. In FIG. 5B adjacent axial rows of aligned tubes are axially spaced one half the length of the tubes. In FIG. 5C the tube ends are arranged in plural spiral patterns. In FIG. 5D the tubes are in a single spiral pattern. In FIG. 5E axially adjacent rows of tubes are not axially aligned to thereby enhance mixing caused by fluid exiting one tube and entering the next adjacent tube. All these configuration have in common the fact that the multiple axial flow paths are provided via a series of blank tubes (without intermediate openings) with each tube extending only a portion of the length of the zone to be treated. These features are believed to enhance gravel placement (*e.g.*,

more consistent flow of slurry, including concentration of sand being delivered, larger volumes of fluid, etc.) and screen assembly.

[0055] The upper and lower ends 34 and 33, respectively, of blank tubes 30 preferably have an arcuate or beveled shape. For example, in FIG. 6 the ends 34 and 33 of the tubes 30 are shown beveled at about 45 degrees. The tubes 30 are shown attached to the inside of the perforated shroud 20 and spaced from the outer surface of the screen 21. In FIG. 7 the tubes are beveled in the opposite direction. However, while the ends of the blank tubes 30 may be arcuate or beveled, they are not limited to such shape.

[0056] In FIG. 8 an alternate configuration of the ends 34 and 33 of axially spaced tubes 30 of FIG. 6 are shown in detail. The beveled discharge end 33 and beveled intake end 34 are parallel to enhance mixing. The arrows 44 are illustrative of flow exiting end 33 and mixing with slurry via shroud perforations 24 to cause uniform distribution of gravel in annular space 23.

[0057] The method of the present invention will be described by reference to FIGS. 1-6. In operation, the improved well screen is assembled and lowered into wellbore 10 on a workstring 28 and is positioned adjacent formation 12. A packer such as packer 26 can be set to isolate the annulus 23 between the perforated shroud 20 and the wellbore 10 as will be understood in the art. Gravel slurry shown as arrows 44 is then pumped down the workstring 28, out through a crossover or the like (not shown), and into the annulus 22 between sand screen 21 and shroud 20. Flow continues into the annulus 23 between shroud 20 and the wellbore 10 by way of perforations 24 in shroud 20. The upper ends 34 of blank tubes 30 are open to receive flow 44 of the gravel slurry as it enters annulus 22.

[0058] The fluid portion of the gravel slurry flowing into the high permeability zones of formation 12 can cause a bridge 32 of gravel to form in annular section 23, thus essentially halting fluid flow through annular section 23. As soon as a gravel bridge 32 plugs annular section 23, the gravel slurry flow 44 will continue to flow down through the blank tubes 30, bypassing the gravel bridge 32, and flow out through the open ends 33 in blank tubes 30 below the gravel bridge 32, thereby allowing further placement of gravel packing sand in the annular space 23 below the sand bridge 32. The flow of gravel slurry (shown as arrows 44) is thus diverted around the gravel bridges until the entire interval in annular space 23 is gravel packed.

[0059] Of course, for every sand size, hole angle, and slurry density relative to completion fluid density, gel rheology, and shunt design, there is a minimum conduit design, fluid slurry velocity, and pumping rate, required to pack a given interval.

[0060] Instead of injecting the gravel slurry down annular section 23 for packing, as described above, the slurry may alternatively be injected down the interior of the screen 21 and up the annular space 23 to be packed in accordance with gravel packing techniques known in the art. In another embodiment, all of the gravel or sand slurry may be pumped only through the blank

tubes 30. The entire annular space 23 can be packed using the tubes 30 to divert gravel pack slurry along the entire interval to be packed.

[0061] The method of the present invention is also applicable to placing a gravel pack in a cased and perforated well drilled in an unconsolidated or poorly consolidated zone. In this embodiment, the particulate material is caused to be uniformly packed in the perforations in the wellbore and within the annulus between the sand screen and the casing. Positioning a conduit or plurality of conduits in the annulus between the sand screen and the casing in accordance with the present invention provides separate flow paths to permit gravel pack slurry to bypass sand bridges which might build up during gravel packing or frac packing and halt the packing process.

[0062] A perforated shroud and sand screen assembly having multiple flowpaths in accordance with the present invention can be assembled from a flat metal sheath with dimensions of desired circumference and length as in the perforated shroud. Perforations or holes of the desired size and density are punched or stamped on the metal sheath. Blank tubes are welded to the metal sheath. The number of tubes can be one or more than one depending on the application and the sizes of the perforated shroud and screen. Both ends of the blank tubes are cut or shaped so that they have an arcuate or beveled shape. The perforated sheath is then rolled up with the blank tubes on the inside wall to be welded into a shroud. Of course, the assembly could be constructed in a variety of other ways.

[0063] The pattern of blank tubes placed on the perforated sheath and the shape of blank tube ends help prevent the risk of the sand control screens getting caught or damaged as they are inserted inside the perforated shroud. These blank tubes act as centralizers for the sand control screen and provide additional integrity for the perforated shroud, if present. Since the blank tubes are not directly attached to the screens in this embodiment, flow and flow area through the screens are not obstructed, especially during production.

[0064] Conventional sand control screens or premium screens, such as POROPLUS™ sintered-metal screens sold by Purolator Facet, Inc., Greensboro, North Carolina, can be pre-installed inside the perforated shroud, if present, before being brought to the well site. The perforated shroud provides protection to the screen during transport. The screens also can be lowered into the wellbore and inserted inside the perforated shroud in the conventional manner. The perforated shroud prevents the screen from contacting the formation wall, minimizing it from damage or plugging.

[0065] The creation of one or more fractures in the unconsolidated subterranean zone to be completed in order to stimulate the production of hydrocarbons therefrom is well known to those skilled in the art. The hydraulic fracturing process generally involves pumping a viscous liquid containing suspended particulate material into the formation or zone at a rate and pressure whereby fractures are created therein. The continued pumping of the fracturing fluid extends the

fractures in the zone and carries the particulate material into the fractures. The fractures are prevented from closing by the presence of the particulate material therein.

[0066] The subterranean zone to be completed can be fractured prior to or during the injection of the particulate material into the zone, *i.e.*, the pumping of the carrier liquid containing the particulate material through the perforated shroud into the zone. Upon the creation of one or more fractures, the particulate material can be pumped into the fractures as well as into the perforations in the casing (for cased wells) and into the annuli between the sand screen and perforated shroud and between the perforated shroud and the wellbore.

[0067] To further illustrate the present invention, and not by way of limitation, the following example is provided. Flow tests were performed to verify the uniform packing of particulate material in the annulus between a simulated wellbore and sand screen. The tests were performed using a fixture, which included an acrylic casing for simulating a wellbore. The acrylic casing had a 8 ½ in.-ID and a total length of 40 ft. A POROPLUS™ sand screen was installed inside the casing. The sand screen had an OD of 5.15 in. and a length of 38 ft. A wash pipe with an OD of 3½ in. was inserted inside the screen. A perforated shroud was not used.

[0068] A high leak-off zone in the casing was simulated by a 2-foot massive leak-off flow cell. The leak-off zone was located about 12 ft. from the inlet. Water (no gel) was used as the carrier fluid and a gravel slurry of 20/40 mesh sand having a concentration of 1 lbm./gal. was pumped into the fixture at a pump rate of about 3.5 barrels/min. Leakoff in the 2-ft. massive leakoff section was 50%.

[0069] Two flow tests were performed to determine the packing performance of the fixture. Baseline testing was first established to determine what the normal gravel packing procedure would accomplish with excessive leakoff. Comparisons were then available for use in analyzing the added packing efficiency provided by the blank tube, multiple path system. Characteristics of the comparison test were the same as in the baseline case except for the addition of 1-inch OD PVC blank tube segments, 6 ft. in length, which were installed in the upper side of the wellbore, across the 2-ft. massive leakoff section. Five axially spaced-apart series of conduits were used, with the number of tubes in each series comprising 3 tubes, 3 tubes, 3 tubes (across the leakoff section), 2 tubes and 2 tubes, respectively (beginning at about the 6 foot location). The blank tubes in each series were positioned equidistantly in the circumferential direction of the sand screen (with the upper and lower ends of the tubes in each series equidistantly situated in the axial direction). The tubes in the adjacent 3-tube series, and the tubes in the adjacent 2-tube series, respectively, were axially aligned, with the end portions of each axially adjacent pair of tubes being spaced about 1 inch apart. The runs were made in a horizontal position.

[0070] In both tests, sand quickly packed around the screen and packed off the massive leak-off area whereby sand bridges were formed. However, in the comparison test the sand slurry flowed through the conduits, bypassed the bridged areas and completely filled the voids resulting

in a complete sand pack throughout the annulus between the sand screen and the casing. In the baseline test, the beta wave started at between the 16 and 17 ft. location. In the comparison test, the beta wave started at the 33 to 34 ft. location. Further, it was observed in the comparison test, that eddy currents were created between the (facing) ends of axially adjacent pairs of (axially-aligned) blank tubes enhancing the effectiveness of the present invention.

[0071] Observations in experiments also showed that an eccentric position of the screen assembly within the wellbore allows a more steady and even placement of gravel within the annulus as compared to a concentric position. In the concentric position (*e.g.*, by means of centralizers), it was observed that the sand slurry was free to flow underneath the centralized tubing, causing more turbulence and erosion on the gravel that had been placed in the alpha wave (*i.e.*, forward direction of gravel placement). With the conventional alpha/beta gravel placement in which the screen assembly is concentric with respect to the well bore, only about 50 to 70% of the screen diameter is covered with gravel bed height during the alpha wave, with the rest to be covered by the gravel during the beta wave (*i.e.*, backward direction). However, if any premature bridging occurs, the beta wave cannot be successfully established, leaving the rest of the screen unpacked. In contrast, with the eccentric position the gravel bed can cover close to or more than 100% of the screen diameter during the alpha wave alone. Besides a steady placement of gravel during the alpha wave, the eccentric position provides additional space for the gravel placement during the beta wave.

[0072] Thus, the present invention is well adapted to carry out the objects and attain the ends and advantages mentioned as well as those which are inherent therein. Of course, the invention does not require that all the advantageous features and all the advantages need to be incorporated into every embodiment of the invention. While numerous changes may be made by those skilled in the art, such changes are included in the spirit of this invention as defined by the appended claims. The invention is not limited to the specific structures and variations disclosed but will permit obvious variations within the scope of the invention as defined by the claims herein.